

contain Mesozoic rocks scarcely more than 60,000,000 years old. This shows that the Rockies are comparatively young mountains—a fact confirmed by their still great height. The much older Appalachian Mountains, extending into the Atlantic Provinces and the Gaspé Peninsula, contain no rocks newer than the Paleozoic, which ended some 200,000,000 years ago; moreover, they are more worn down by erosion.

MOUNTAINS AND METALS

Mountain building is usually accompanied by igneous activity—volcanic eruptions and other movements of molten material from beneath the earth's crust. Usually, scientists believe, the tremendous weight of rock pressing down on this material keeps it in a solid state; but upward warping reduces this pressure, allowing it to liquefy and flow as magma: the resulting intrusions may be rich in valuable metals.

Many important mineral deposits are in the form of *veins*, regular-shaped intrusions which frequently occupy fractures or faults. Some are formed in zones of fragmented rock, either in faults or in material ejected from volcanoes. Other deposits may fill cavities formed by the action of groundwater in dissolving limestone.

Some deposits are formed by the process of *replacement*. This is a slow piecemeal process whereby mineral-bearing solutions work their way through cracks and pores, dissolving the existing rock and substituting other minerals. Most replacement deposits are irregular in shape, without the clearly defined walls of vein deposits. Many replacement deposits are too small or too low in metal content to have commercial value; but some are important sources of copper, lead, zinc and precious metals.

MINERALS FROM SEDIMENTS

Metals and other useful minerals are also mined from sedimentary deposits. Sometimes a whole deposit, consisting of salt, limestone or some other industrial mineral, can be mined and used. Chalk is a form of limestone produced by the age-long accumulation of shells from countless tiny sea animals. The last part of the Mesozoic era, known as the *Cretaceous* period, is named from the chalk deposits formed at that time in northwest Europe.

Other sediments, known as *detrital deposits*, contain concentrations of heavy minerals such as iron, gold, platinum and uranium. Unconsolidated deposits of this kind, like the gold-rich gravels that yielded fortunes in the Klondike, are called *placers*. Most placers are found in ancient river beds, sometimes covered by other material deposited by glaciers.

Some minerals are deposited by chemical precipitation in surface water. One example is limonite, a type of iron ore found in "bog iron" deposits in Quebec's St. Lawrence valley and elsewhere in Canada. This is formed where water seeping through rocks dissolves iron from them, then flows into bogs or pools containing decayed vegetable matter. The dissolved iron reacts with the carbon in this material to form a heavy brownish compound that settles on the bottom.

Coal, petroleum and natural gas are found in sedimentary deposits and nowhere else. These substances are known as *fossil fuels*, because they were formed from organic material trapped and buried with sediments laid down many millions of years ago. Part of the Paleozoic era is generally called the *Carboniferous* ("coal-bearing") period, because of the large

coal deposits formed from the swamps and forest of that time.

THE GEOLOGY OF CANADA

A dominant feature of Canada's geology is the *Precambrian Shield*, which extends around Hudson Bay from the Arctic Ocean to the lowlands of southern Ontario and Quebec. Also known as the *Canadian Shield*, this is the core of the North American continent, containing some of the oldest rocks in the world. Over long ages these have been greatly eroded, then scraped almost bare by glaciers during the *Pleistocene* period which began perhaps 1,200,000 years ago.

The Canadian Shield is one of the most productive mining areas in the world, especially rich in such important base metals as copper, nickel, iron, lead and zinc. Among the other minerals produced are gold, silver, cobalt, asbestos, uranium, platinum, titanium and molybdenum.

Much of the soil from the Canadian Shield was deposited on the *Interior Plains*, producing the fertile agricultural land of the Canadian Prairies. Beneath this soil are Paleozoic and Mesozoic sediments that produce most of Canada's petroleum and natural gas. The Athabasca oil sands, extending more than 100 miles along the Athabasca River in northern Alberta, were deposited during the Cretaceous period.

Besides oil and gas, the Interior Plains contain enormous reserves of potash, especially in southern Saskatchewan. Other minerals produced on these plains include zinc, lead, salt, gypsum and limestone. Coal has been mined in many places in this region.

West of the Interior Plains is Canada's newest mountain area, the *Cordillera*, thrust up about the end of the Mesozoic era. It consists of three parallel systems trending roughly northwest. The eastern system includes the Canadian Rockies and the Franklin, Richardson and Mackenzie Mountains of the Northwest Territories and the Yukon. In the western system are the Coast Mountains of British Columbia's west mainland, the St. Elias Mountains in the southwest Yukon, the Queen Charlotte Islands and Vancouver Island. The interior system contains the lower mountain ranges, plateaux and plains of the interior British Columbia and the Yukon.

The Cordillera is an important and promising mining region. The western system yields such minerals as copper, gold, molybdenum and iron, while the interior system produces chiefly lead, zinc and silver—frequently along with cadmium, antimony and bismuth. Coal is also mined at many points.

Bordering the Atlantic coast, the *Appalachian Region* comprises the Atlantic Provinces and southeastern Quebec. This was formerly part of a long submerged trough that filled with sediments during Paleozoic time, more than 200,000,000 years ago. These were then uplifted to form the Appalachian Mountains of the Atlantic seaboard, now greatly worn down by erosion.

The Appalachian Region has yielded many valuable minerals, including many tons of iron ore from the now-closed Wabana mine in southeast Newfoundland. The region is still an important source of base metals, notably copper in the Gaspé Peninsula. Newfoundland also produces asbestos and all of Canada's supply of industrial fluorite.

In the *St. Lawrence and Hudson Bay Lowlands*, bordering the Canadian Shield, the



youngest rocks likewise consist of Paleozoic strata laid down when these areas were submerged by shallow seas. As on the Interior Plains, the rich soil in these areas was largely scraped from the Canadian Shield by the huge Pleistocene ice sheets.

A number of non-metallic minerals are mined in the St. Lawrence Lowlands, such as salt and gypsum. Petroleum and natural gas have been produced for many years southeast of Lake Huron, and have also been discovered along the St. Lawrence River. In the Hudson Bay

Lowlands are deposits of gypsum and lignite, not yet exploited.

In Canada's extreme north is the *Innuition Region*, including most of the Queen Elizabeth Islands. This is a region of folded rocks of varying ages dating from Precambrian to early Cenozoic (or Tertiary) times: the most prominent reminders of this folding are the low, ice-capped mountains of northern Ellesmere Island.

Serious and scientific mineral exploration has started only recently in the Innuition Region. Coal has been found in many places, and the geology of this area is favorable to the discovery of oil and natural gas.

Bordering the northern edge of the Innuition Region is the *Arctic Coastal Plain*. This is an area of sand and gravel deposited in comparatively recent times, late in the Cenozoic era. It slopes down gently into the Arctic Ocean, where it may reach far out onto the continental shelf. South of the Innuition Region are the *Arctic Lowlands and Plateaux*, whose youngest rocks were formed about 350,000,000 years ago.

GEOLOGISTS AT WORK

Increasing our knowledge of Canada's geology are scientists of the Geological Survey of Canada, a branch of the Department of Energy, Mines and Resources. Founded in 1842, the Geological Survey is the oldest scientific agency of the Canadian government, 25 years older than Confederation. From a two-man survey in 1842 it has grown into a widely renowned scientific organization with a continuing staff of more than 450.

The Survey engages in geological mapping, detection, interpretation and research, including

work in mineralogy, paleontology and aspects of geophysics, geochemistry and physical geography. Thus it maintains a comprehensive national and regional inventory of rock formations and other deposits, their structures, contained minerals and the landforms containing these formations. The Survey also furnishes vital information to Canada's mining industry.

Besides aiding in the exploitation of Canada's vast mineral wealth, the Geological Survey assists in the inventory of our water and energy resources. Moreover, by providing information on the physical and chemical characteristics of rock structures, subsoils and landforms, it assists in pollution control, construction engineering and other essential activities. Thus it plays a most important part in the wise use and management of our natural resources.



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We usually think of this "solid earth" as something unchanging—until an earthquake or some other huge disturbance occurs. Volcanic eruptions have blasted islands out of the sea and given birth to new ones as observers watched in wonder. But less spectacular changes go on steadily all around us, remaking the face of the earth over hundreds, thousands and millions of years.

Everyone has seen *erosion*, the wearing away of rocks and soil by water, winds, heat and cold. Soil itself is partly the product of erosion, which splits and fragments solid rock into tiny particles of sand. In most places layers of soil or *overburden* cover the hard bedrock of the earth's crust, leaving only occasional *outcrops* of rock exposed to view.

During the ice ages which ended less than 10,000 years ago, enormous glaciers caused erosion on a spectacular scale as they scraped and scoured large areas of the world. Except in some mountain regions and near the poles, we no longer see glaciers at work; but everywhere in Canada we can still observe the splitting and crumbling effects of frost.

WATER AT WORK

This splitting and crumbling is a form of *weathering*, a type of erosion which results when rocks or buildings are exposed to air and moisture. Another form of weathering occurs when water from the atmosphere dissolves away portions of rock. When combined with carbon dioxide from the air, water will dissolve most substances to some extent; and this solvent action is increased by soil acids produced by plants and picked up by streams and groundwater.

But more important than this chemical erosion is the mechanical action of moving water. Grain by grain, rain loosens particles of soil and rock and washes them into our rivers, lakes and coastal waters. A heavy storm may strip large areas of many tons of soil, causing landslides and carving out gullies. Rivers carry away and redeposit this material farther downstream or out to sea, creating deltas, beaches, sandbars and other layers of sediment.

In rapids and waterfalls, the powerful rush of water loosens blocks of solid rock, rolling and tumbling them along the river bed. As they bounce and strike against each other, they are gradually cracked and worn into smaller fragments, pebbles and grains. These act as scraping and cutting tools, slowly wearing down the hardest bedrock or boulders in a stream.

Rivers undercut their banks as they hurry to the sea, sometimes widening their valleys as they carve new channels along the way. Meanwhile fast-flowing streams slowly deepen their valleys, and the sediment scooped up accumulates on the bottoms of lakes and makes them shallower. Around our lakes and along our sea-coasts, waves and currents produce similar effects as they pound the shoreline and shift great quantities of sand.

WINDS AND GLACIERS

In many regions, winds are another important cause of erosion. Dust storms are a well-known hazard in some farming areas, blowing away valuable top soil. In desert regions sandstorms not only shift sand from place to place, but also act like a sandblast that scours and polishes larger rock fragments and outcrops of bedrock.

Glaciers still cause erosion in Canada's western mountains and in parts of the arctic. Near the higher mountain summits are masses of ice known as *alpine glaciers*, which survive even the hottest summers. Larger glaciers, known as *ice-fields*, are found in some mountain areas and over parts of Baffin Island, Greenland and other arctic regions.

Glaciers form wherever more snow falls in winter than melts in summer. The weight of fresh snow presses down upon the older, underlying layers, compacting them and turning them to solid ice. As snow continues to fall, the accumulating weight of snow and ice makes the lower part of the glacier flow like stiff molasses, until the ice melts at warmer altitudes. If fresh snow accumulates faster than the ice melts, the glacier grows and advances; if the ice melts more quickly, then the glacier shrinks and retreats.

The slow, creeping flow of ice in a glacier causes erosion in much the same way as a fast-running stream. It picks up and carries along loose fragments of rock and other material, dropping them elsewhere when the ice melts. Caught and frozen in the glacier, these fragments act like bits in some enormous cutting tool.

The large fragments scrape the soil and bedrock in the glacier's path, gouging and chiseling as they are pushed along. Smaller particles scour and polish rocky surfaces, rounding and smoothing rough edges and cutting long scratches known as *striae*.

GLACIERS AT WORK

Glaciers often follow old valleys originally carved by rivers in the usual "V" shape. But the grinding flow of ice gouges and widens the valley bottom, reshaping the "V" into a "U". In this way it may cut off the lower ends of adjoining valleys, leaving them to end abruptly in a sharp drop. Such valleys are known as *hanging valleys*, and often give rise to spectacular waterfalls.

At the upper end of a glacier, ice may freeze in cracks or around projecting rock. The glacier then may pluck away huge chunks of the mountain side, leaving semicircular basins called *cirques*. As temperatures change, these may later fill with water to form *cirque lakes*.

Today, when we read about glaciers, we are apt to think only of the arctic or of high mountain ranges. But during the several ice ages much of the Northern Hemisphere was covered by ice. Our Great Lakes were left behind by the Laurentide Ice Sheet, which covered half of North America and retreated only some 10,000 years ago. This ice sheet not only re-

sculptured the landscape, but the weight of ice was so enormous that it depressed the earth's crust; and so it formed deep basins that filled with water as the ice retreated.

PRODUCTS OF EROSION

The loose rock, gravel and other material deposited by glaciers form ridges called *moraines*. Those left at the lower end or foot of the glacier are known as *terminal moraines*, and those left along the sides are *lateral moraines*. Loose boulders and other stray chunks of rock, dropped in the middle of a field or some other unlikely spot, are known as *glacial erratics*.

In mountain areas we can observe still other effects of ice. Especially on cold summer nights, frost may split off small angular fragments which tumble down the mountain face and accumulate at the bottom of cliffs. Large piles of these fragments are called *talus slopes* by geologists and *scree slopes* by mountaineers.

Sometimes many tons of rock, soil and gravel will plunge down a cliff or mountain in a sudden, destructive landslide. Less spectacular is the slow downward shifting of loosened material by a process known as *creep*. When it reaches a stream—perhaps washed in by rain or melted snow—this debris adds to the sediments already eroded by the stream itself. Thus eroded material from many different sources makes its way slowly towards the sea.

This material does not move evenly, however. As a stream or current slows down, large stones and pebbles soon fall to the bottom or come to rest along the shores or bordering beaches. Coarse sand and gravel are carried farther before settling out, while very fine sand and other

light particles may be swept far out to sea. Streams and currents thus behave like a natural centrifuge, sorting different sediments according to weight and size.

Much of the material carried to the sea remains dissolved in water, so adding to the ocean brine. This contains not only common salt, but also traces of almost every element known. Some of these substances, though, are precipitated out of the water by chemical reactions, or left behind when it evaporates from shallow tidal ponds. Thus they form deposits of calcium carbonate, salts and other chemical substances.

HOW ROCKS ARE FORMED

Layers of gravel, sand, calcium carbonate and other material are deposited first as *unconsolidated* sediments. These may be eroded further, or else they may be buried under a growing accumulation of other sediments. Beneath the increasing weight and pressure of this material, the deeper sediments become consolidated into rock. Sandy sediments are thus consolidated into sandstone, while deposits of calcium carbonate become limestone.

Rocks formed in this way are known as *sedimentary rocks*. Sedimentary rocks, however, are not the only kind we can observe. *Igneous rocks* are formed quite differently, by the upwelling of molten material or magma from beneath the earth's crust. This occurs in a spectacular way when a volcano erupts, spewing forth ashes and lava. But it also occurs beneath the surface, producing rocks which may later be exposed to view by erosion.

Igneous rocks are so named from the Latin word *ignis*, meaning "fire", referring to the hot

interior of the earth where they originate. Appropriately, igneous rocks formed by volcanic activity are known as *volcanic rocks*. Those formed beneath the surface are called *intrusive rocks*, because of the way they intrude into other rock formations.

Plutonic rocks are coarse-grained intrusive rocks, such as granite or diorite, which often become exposed in deeply eroded mountain regions, or in regions like the Canadian Shield which were formerly mountainous. Smaller bodies of plutonic rock are known as *stocks*; larger ones, with areas of more than 40 square miles, are called *batholiths*.

COOLING, HEAT AND PRESSURE

The large grains or crystals in plutonic rocks show that their molten material must have cooled slowly, thousands of feet below the surface. Closer to the surface, faster cooling produces finer-grained intrusive rocks in three different forms. These include long, narrow *dykes* that fill breaks or fractures across other rocks; thin *sills* injected between rock strata or flows of volcanic rock; and small, irregular masses with no special name.

Molten lava, escaping from volcanoes and fissures, cools quickly as it flows over the land surface or under water. Thus it solidifies into fine-grained rocks resembling those in dykes and sills. Other volcanic rocks are formed from accumulations of ash and larger fragments hurled forth by many volcanoes.

Under heat or pressure, sedimentary and igneous rocks may both be transformed into *metamorphic rocks*. In this way, for example, limestone becomes marble and sandstone becomes quartzite. Such changes occur as the

new conditions cause minerals to recrystallize and new chemical compounds to form in the rocks.

The earth's rocky crust, perhaps 50 miles deep, is constantly under shifting pressures and stresses, from above and from below. These twist and crack the rocks in many places, deforming and warping the crust on a sometimes massive scale. From above, these pressures are caused largely by the increasing weight of accumulating sediments. This tends to depress the crust, just as the enormous ice-age glaciers did.

On the other hand, erosion wears away rocks and soil in highland areas, thus lightening the load. With the weight and downward pressure thus reduced, the crust in these areas slowly rebounds and yields to upward pressures from below. In this way, land surfaces worn almost flat by erosion are slowly uplifted to form high tablelands or plateaux. This uplifting causes streams to flow faster, cutting deeply into the new plateaux and carving them into a second generation of mountains and valleys.

FRACTURES, FAULTS AND FOLDS

Vertical and horizontal stresses produce many *fractures*, *faults* and *folds* in the earth's crust. Fractures, or joints, range in size from small cracks to fissures more than 100 feet long. They commonly occur in groups, with several fractures running parallel or intersecting one another at roughly uniform angles. Continued stress may shift the rock on one side of a fracture, so producing a *fault*. *Folding* is a gentler process, in which layers of rock yield slowly like hard candy.

Large faults extend for several miles, and the largest for hundreds of miles. Movement along such faults causes intense vibrations or earthquakes, and the displacement of rocks at one side or another can be measured in hundreds of feet, or even in miles.

The walls of a fault are usually smooth and grooved, with polished surfaces known as *slickensides*. The movement along a fault often grinds the rock to form a clay-like deposit of crushed rock, called *gouge*. This may be only a fraction of an inch thick, or as thick as several feet.

Instead of producing gouge, the movement may form a *shear zone*—a band of sheared or sliced rock between the opposite sides of the fault. Sometimes this intervening rock is crushed into angular fragments, forming what is called a *crushed or brecciated zone*.

Under enormous steady pressure, solid rock buckles slowly into folds which may be miles wide. A fold that arches upward is called an *anticline*, while the downward fold or trough beside it is known as a *syncline*. This folding process often tilts beds of sedimentary rock far from their original horizontal position, sometimes turning them upside down.

Fracturing, faulting and folding play a leading part in the complex process of *mountain building*, which geologists call *orogeny*. By this process, huge masses of sedimentary rock are uplifted and cast into folds and fault blocks; or, as we have seen, older mountain areas worn down by erosion are again uplifted and carved into new mountains. Frequently, as in western Canada, high mountains are formed from sediments laid down earlier in a submerged ocean trough.

THE EARTH'S CALENDAR

Sedimentary rocks contain fossils—remains and traces of plant and animal life—which tell us a great deal about conditions when the sediments were laid down. For example, fossils of giant tree ferns found in Greenland reveal that the climate there was once quite warm; and fossils of shellfish and other sea life tell us that high mountain regions were once under water.

Most recently formed were the uppermost layers of rock, laid down in *beds* or *strata*. The newest layers, less than 4,000,000 years old, contain fossils of plants and animals much like those we see today. The strata beneath contain less familiar forms, such as huge titanotheres, many-toed horses and other extinct mammals; and deeper still are fossils of dinosaurs, giant tree ferns and other strange animals and plants.

At still lower levels there are fewer fossils of land-dwelling forms, but plenty of fossil fishes and other sea-dwelling organisms. The oldest fossils, more than 500,000,000 years old, are of very lowly and simple organisms such as algae and primitive invertebrates. The most ancient sedimentary rocks, more than 3,500,000,000 years old, contain no visible traces of life.

This orderly sequence of fossil-bearing strata, layer upon layer, is a key to the history of the earth. Nowhere is this history complete, and in most locations many of the pages are missing. However, by comparing rocks in many different parts of the world, geologists have worked out a time scale in which every layer or stratum of rock has its place.

Rocks are assigned to different periods, which in turn are grouped into different geological eras. The latest of these is the *Cenozoic* (mean-

ing "recent life") era or age of mammals, stretching back some 60,000,000 years. Preceding that was the *Mesozoic* ("middle life") or age of dinosaurs, lasting about 140,000,000 years; and before that was the *Paleozoic* ("ancient life") or age of fishes and other water-dwelling animals, which lasted about 300,000,000 years.

First of all came *Precambrian* time, stretching back five times further into the past than all the rest of the geological calendar. Precambrian rocks are so named because they underlie those of the Cambrian period, the earliest division of the Paleozoic era.

The lack of fossils in Precambrian rocks, and the way these rocks are deformed, make it difficult to assign them to shorter time periods. In parts of Canada, however, geologists have distinguished four divisions: the *Hadrynian*, *Helikian*, *Aphebian*, and the Early Precambrian or *Archean* ("ancient" or "beginning") division. The first three are often grouped together as the Late *Precambrian* or *Proterozoic* ("fore life").

DATING THE ROCKS

How do geologists calculate the age of rocks? Their first estimates were based on observations of the average rate at which sediments accumulate today. When they applied this rate to the enormous thicknesses of sedimentary rocks, they realized that the earth must be many millions of years old. Strata less than 500,000,000 years old can often be dated by the types of fossils found in them. A modern method, which can be applied to all kinds of rocks, is the measurement of the decay of *radioactive metal isotopes*—uranium, rubidium, potassium.

The age of a mountain chain can often be estimated from the age of the rocks uplifted to form it. The Canadian Rockies, for example,

ERA	PERIOD	CHARACTERISTIC LIFE	TIME IN YEARS
CENOZOIC	RECENT	Man	1,200,000
		Mammals and modern plants	
	TERTIARY	Miocene	65,000,000
		Oligocene	
		Eocene	
MESOZOIC	CRETACEOUS	Reptiles and gymnosperms	225,000,000
	JURASSIC	Archosaurs and cycloptera	
	TRIASSIC	Archosaurs and cycloptera	
PALEOZOIC	PERMIAN	Archosaurs and cycloptera	145,000,000
		Archosaurs and cycloptera	
	CARBONIFEROUS	Archosaurs and cycloptera	440,000,000
		Archosaurs and cycloptera	
	DEVONIAN	Fishes	570,000,000
PRECAMBRIAN	SILURIAN	Higher invertebrates	
	ORDOVICIAN	Higher invertebrates	
	CAMBRIAN	Primitive invertebrates and algae	1,370,000,000
PROTEROZOIC	HADRYNIAN	Stromatolites	
	HELIKIAN	Algae and other?	
	APHEBIAN	Algae and other?	2,490,000,000
ARCHEAN			
			3,200,000,000 or more